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Author(s): Mukundan, Rangachary
Borup, Rodney L.
Spernjak, Dusan
Wu, Gang
Steibach, Andrew
Zelenay, Piotr
Hussey, Daniel
Jacobson, David

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NEUTRON IMAGING TO OPTIMIZE PEM FUEL CELLS PERFORMANCE

Rodney Borup[a], Rangachary Mukundan[a], Dusan Spernjak[a], Gang Wu[a], Andrew Steinbach[b], and Piotr Zelenay[a], Daniel Hussey[c], David Jacobson[c]

[a]Los Alamos National Laboratory

[b]3M Company

[c]National Institute of Standards and Technology

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Outline

- Introduction
  - Visualizing water using neutron imaging
  - Role of water/Gas Diffusion layers (GDL) in PEM Fuel cells
- Neutron visualization applied to
  - Standard Pt/C based MEAs
  - 3M NSTF MEAs
  - Non-precious metal catalyst MEAs
- Summary / Future Work

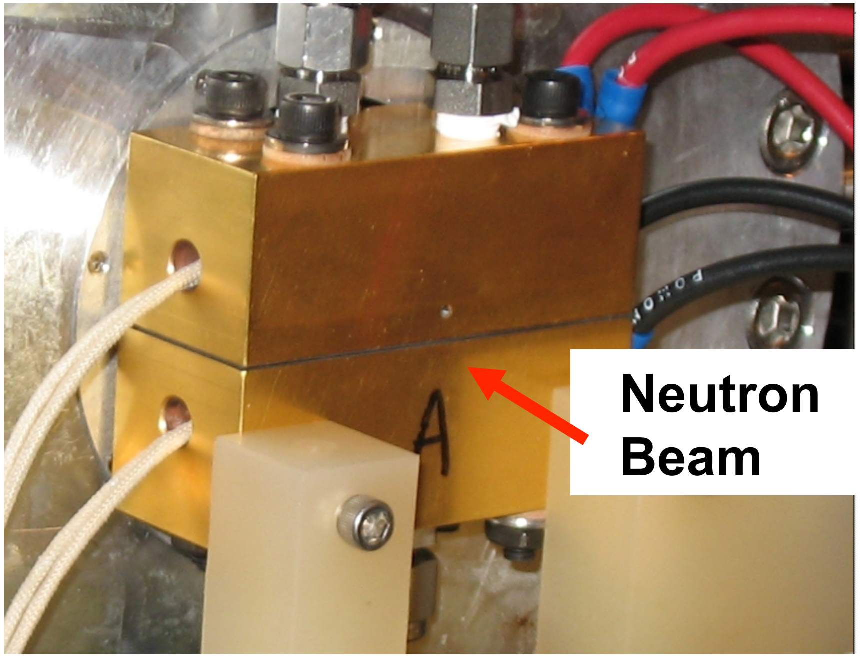
Acknowledgements

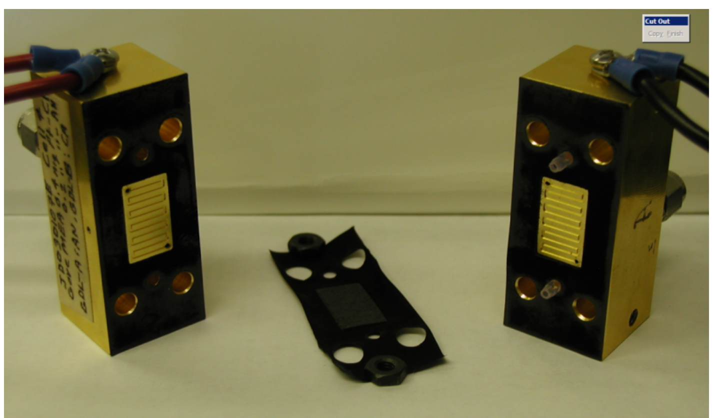
U.S. Department of Energy for funding through **Office of Fuel Cell Technologies (EERE). Nancy Garland and Dimitrios Papageorgopoulos**

Visualizing Water Using Neutron Imaging

Fuel Cell Design for High-Resolution Neutron Imaging

Previous work, XDL 25 μm detector





Advantages:

- Observe and distinguish between MEA and anode and cathode GDLs and flow fields in x-section
- The high resolution (~13 μm) MCP detector provides the capability of resolving the water content of these thin fuel cell components
- 1 mm X 1 cm slit. L/D= 6000; L/D=600

Fuel Cell Design Constraints:

- Maximum field of view is 3.5 cm X 3.5 cm
- Outermost fuel cell edge in neutron beam path should be no more than 3 cm from detector for good imaging
- The neutron beam should not pass through more than 1 cm of cumulative liquid water and there should be minimal hydrogen containing compounds in the neutron beam path

Our Cell:

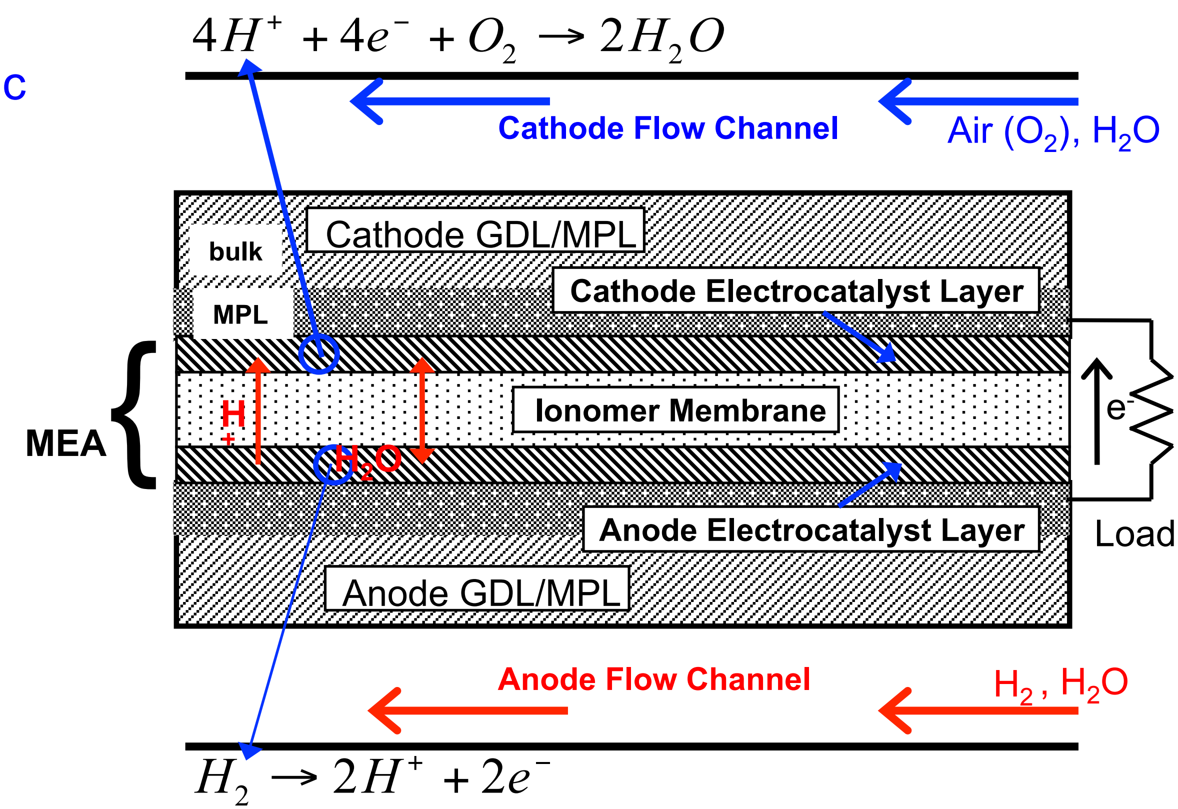
- Active area: 2.25 cm^2, 1.12 cm X 2.0 cm
- Hardware = gold plated aluminum, gaskets = fiberglass reinforced PTFE
- ~ 1 cm active-area beam path length
- Shallow single serpentine flow field channel (0.6 mm wide X 0.25 mm deep). Realistic pressure drop: ~ 1/3rd that of the 50 cm^2 cell

Role of water/Gas Diffusion Layers (GDL) in PEM Fuel cells

Water in PEM Fuel Cells

- H_2O fluxes: in An & Ca gas feed stream, electro-osmotic drag (An→Ca), Ca formation, back-diffusion (Ca→An), and in An & Ca exhaust streams

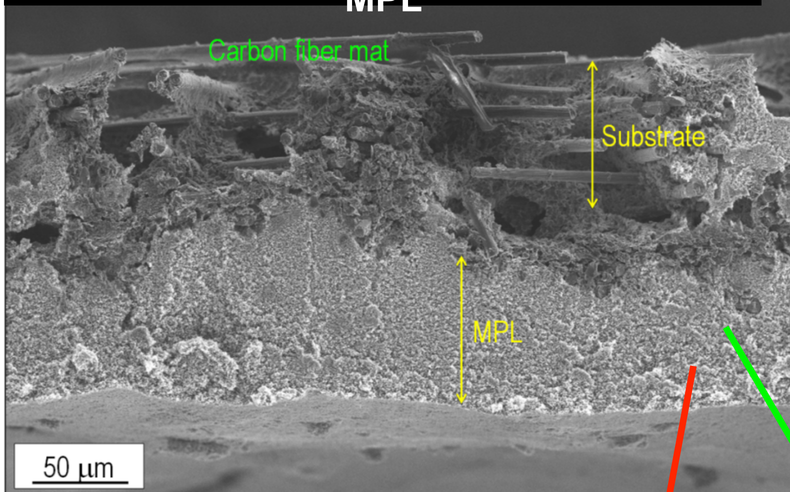
- **GDLs** are responsible for ensuring optimal H_2O transport (liquid and vapor) in and out of the MEA, without inhibiting reactant and product transport



Critical for very thin (NSTF) and
very thick (non-precious metal) catalyst layers

Water management in conventional Pt- based MEAs Gas Diffusion Layer (GDL) modifications

GDL Cross-section SEM: Substrate + MPL



MPL is "loosely packed " carbon black + PTFE; Substrate is carbon fiber mat "filled" with PTFE

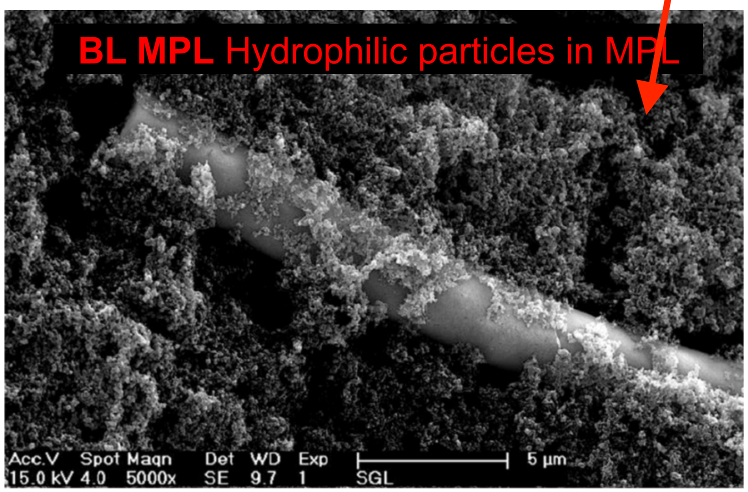
Keep membrane and catalyst layer ionomer wet
Keep liquid water out of cathode catalyst layer
Avoid liquid water accumulation in GDL and flow fields

SGL/LANL : Published papers on additives to the MPL to improve water management

3M : Published papers on water removal through anode (either vacuum or special anode GDLs)

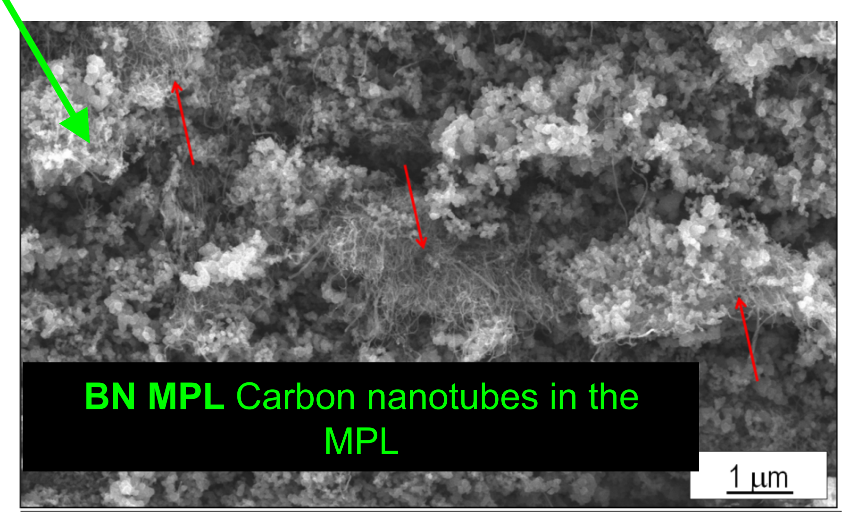
These strategies are directly applicable to thick non-PGM electrodes

BL MPL Hydrophilic particles in MPL



10% Aluminosilicate fibers mixed in with standard MPL mixture of carbon black + PTFE (23w%). MPL treated at 350 °C

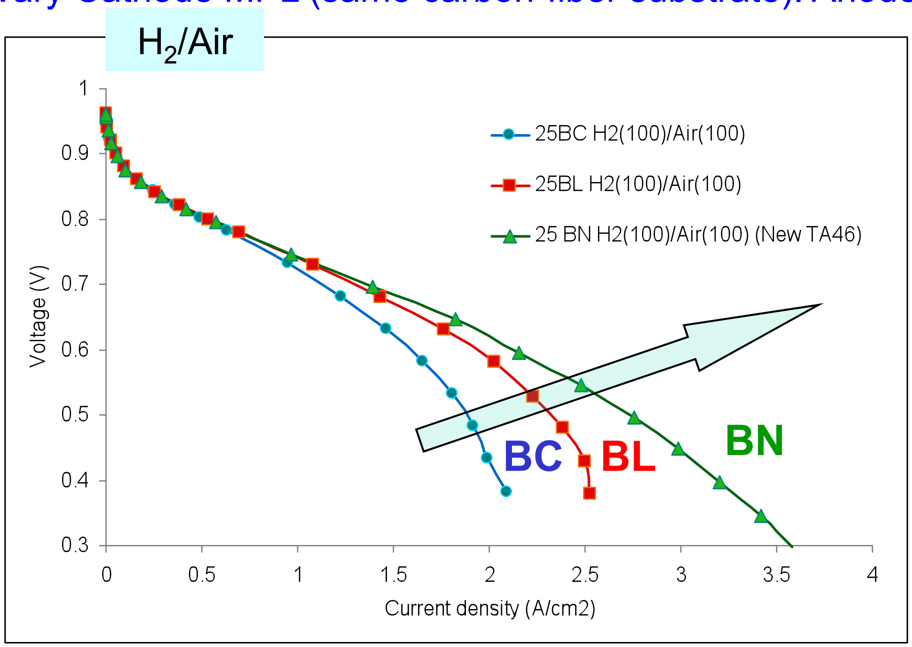
BN MPL Carbon nanotubes in the MPL

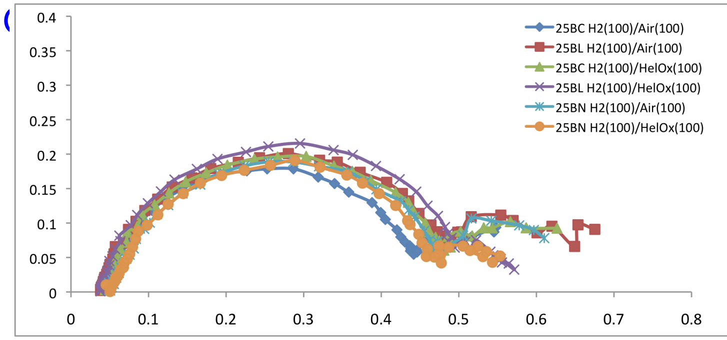


MPL comprised of loosely packed carbon black particles that surround CNT "bundles" (red arrows) – CNTs are not homogeneously distributed within the MPL.

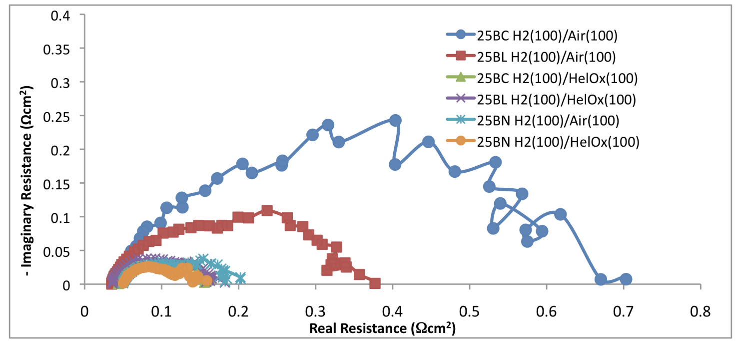
Performance of various GDLs (Conventional Pt MEA)

Vary Cathode MPL (same carbon-fiber substrate). Anode (





0.1 A/cm²



1.4 A/cm²

Performance improvement at high current for 25BL and 25BN in H_2/ Air.
Similar performance for 3 GDLs at low current densities and in HelOx

- **25BC** = standard MPL (carbon+PTFE+binder) BASELINE
- **25BL** = standard MPL with hydrophilic treatment: Mass-transport improvement; Durability issues
- **25BN** = standard MPL with C-nanotubes: More mass-transport improvement; Durability good

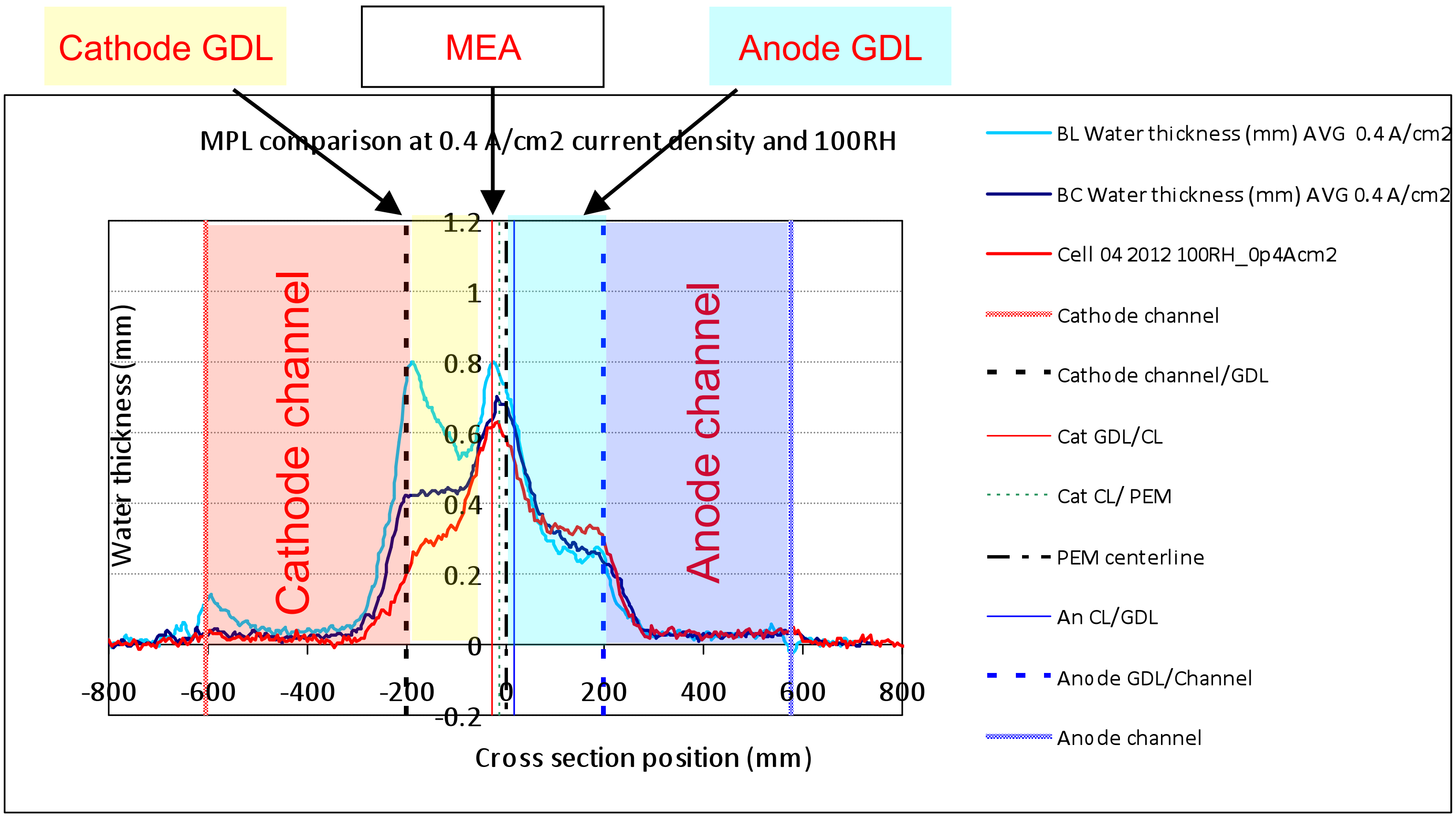
50 cm² cell, quad serpentine, MEA = Gore PRIMEA A510.2/M710.18/C510.4; 80° C, 100% RH, 1.2/2 stoich, 28.4 psi backpressure

Standard Pt/C MEAs

Water profile across the cell thickness at fixed current

- **25BC** = standard MPL (carbon+PTFE+binder): Higher CL water content than BL or BN
- **25BL** = standard MPL with hydrophilic treatment: Liquid water in the MPL
- **25BN** = standard MPL with C-nanotubes: Least amount of water everywhere

2.5 cm^2 cell, single-serpentine, MEA = Gore PRIMEA A510.2/M710.18/C510.4 80° C, 100% RH, 100/200 sccm, zero backpressure

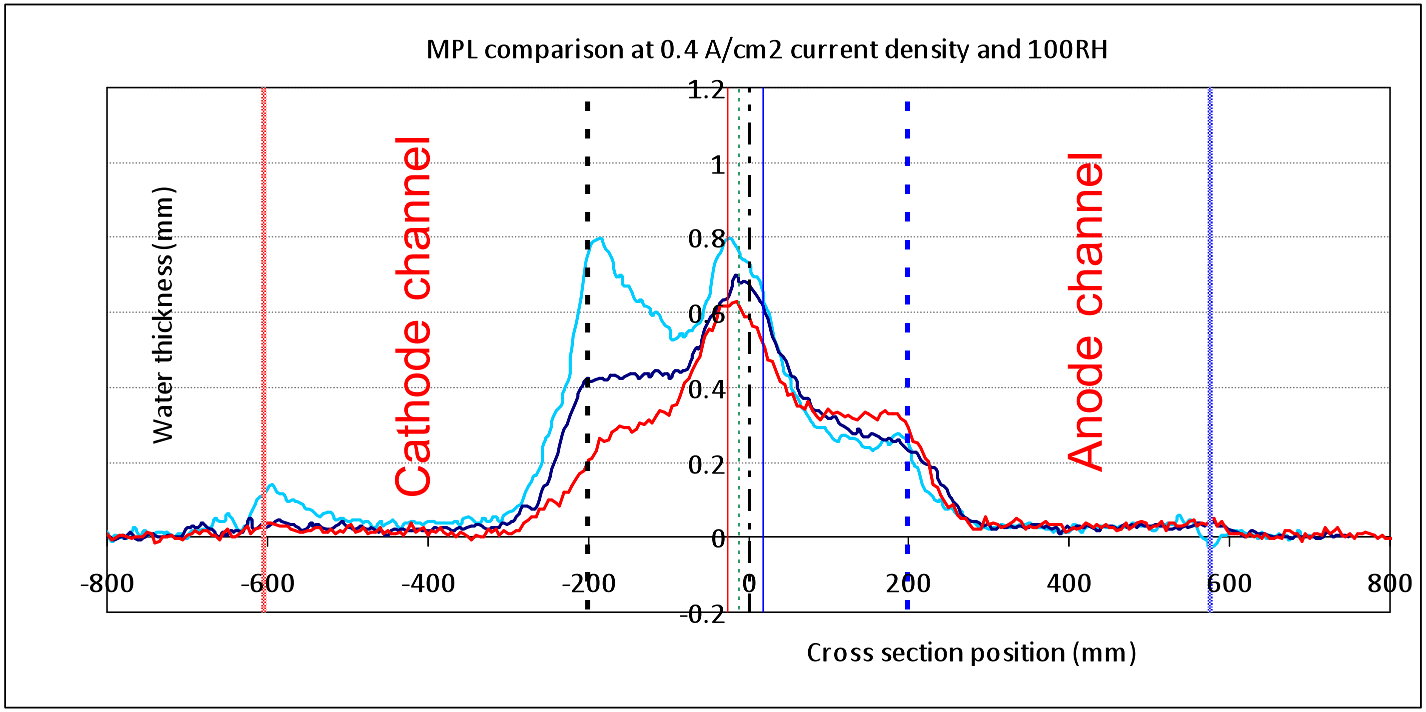


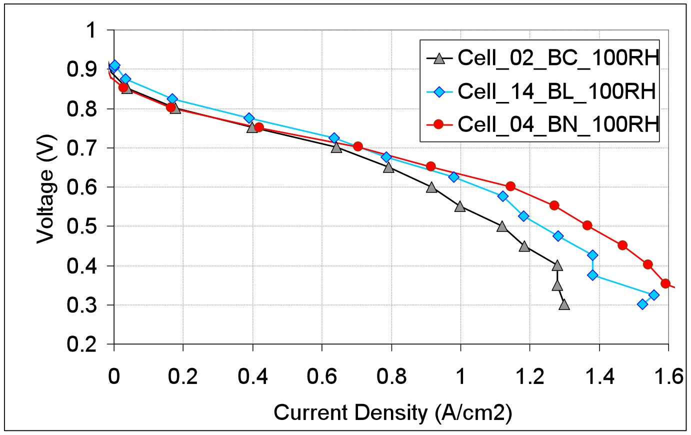
Low current performance un-affected by water

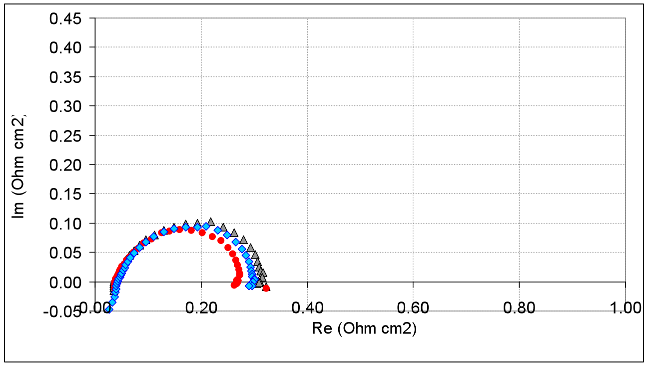
0.4 A/cm²

Maximum water observed in BL GDL (hydrophillic channels in MPL)

Little difference in performance observed







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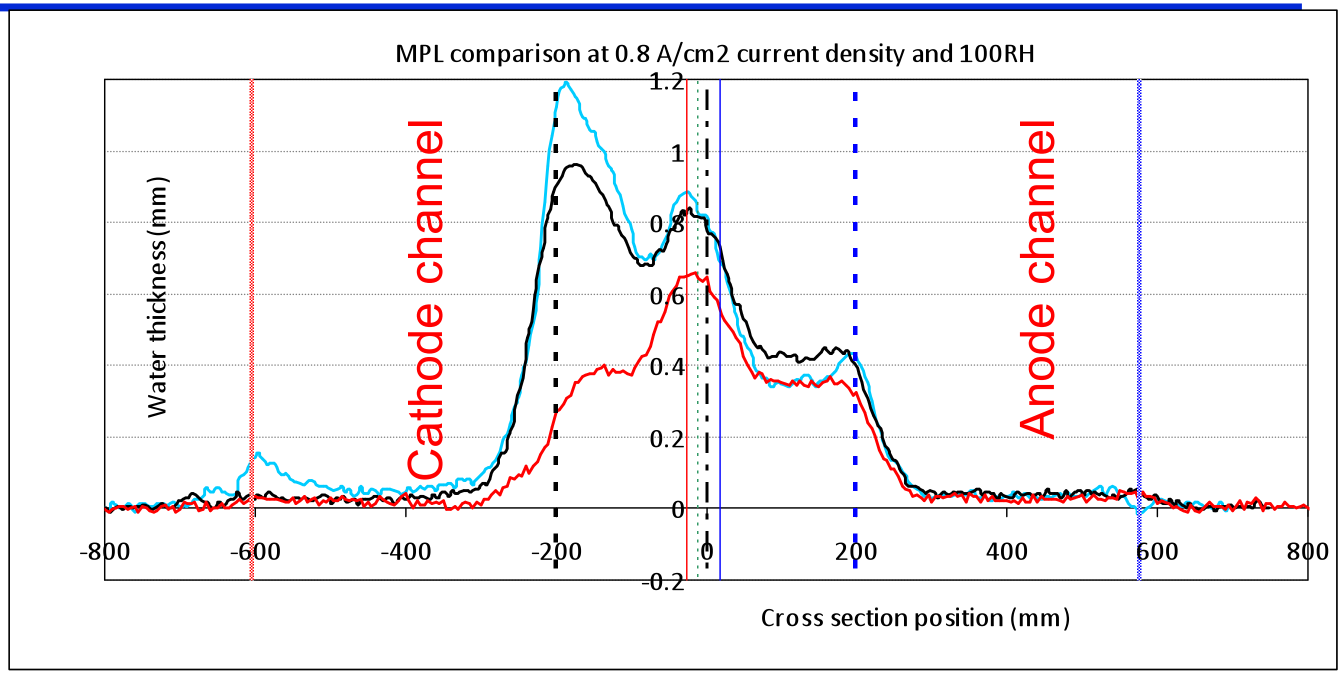
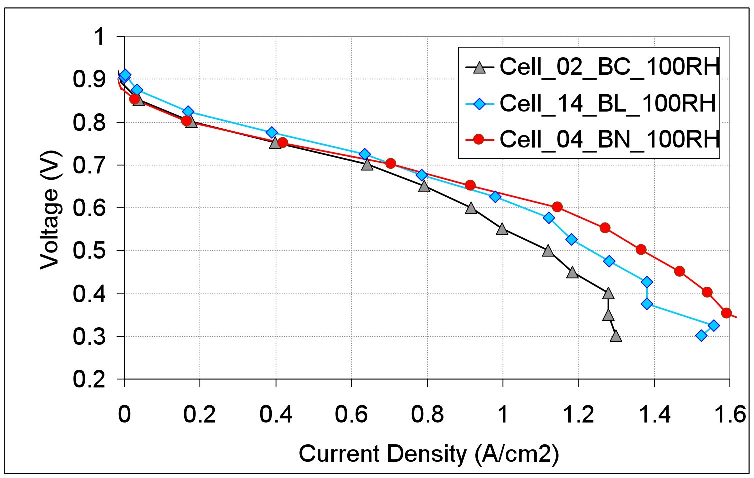
Performance improved with decrease MEA water content

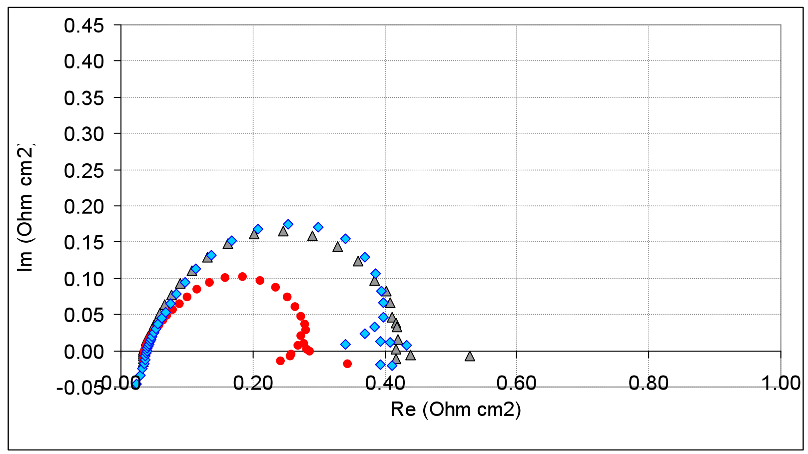
0.8 A/cm^2

Maximum water observed in BL GDL and minimum water observed in BN GDL

Catalyst/MEA water is lowest in BN GDL and performance is best





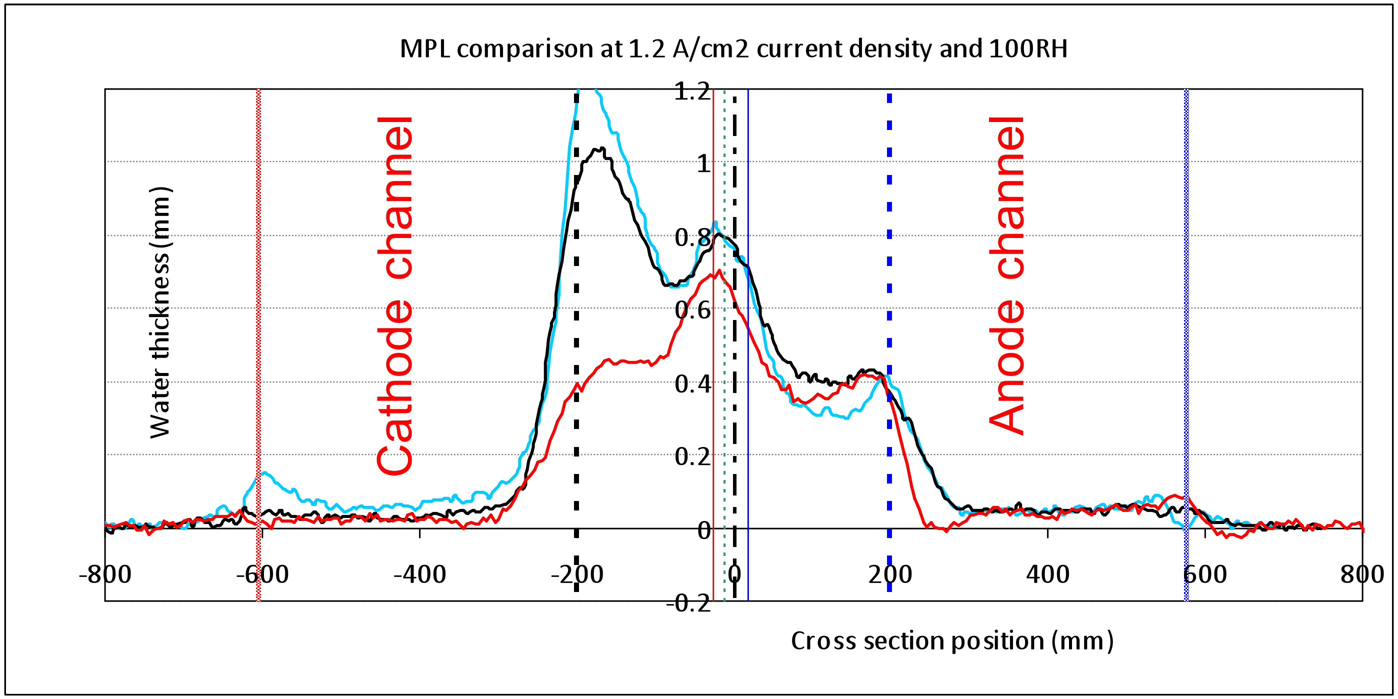


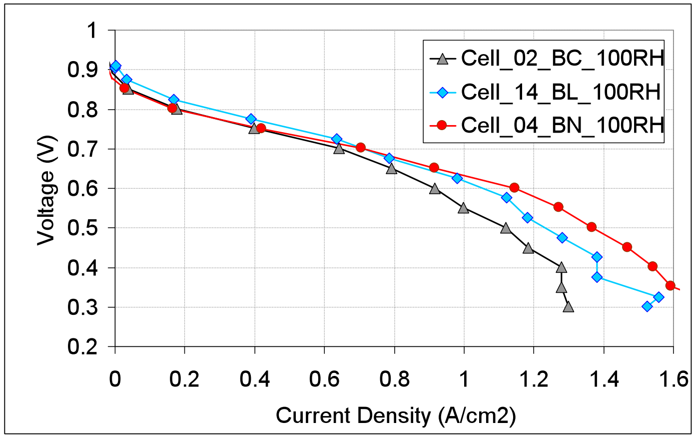
Performance improved with decrease MEA water content

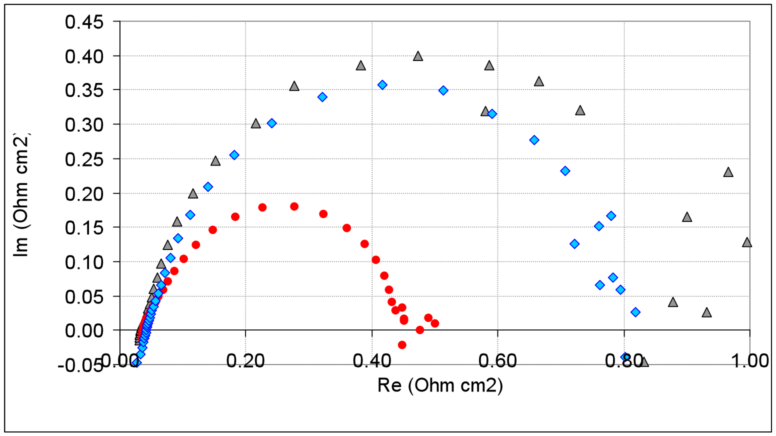
1.2 A/cm²

Water content initially increase with increasing current and then stabilizes due to heat generated

Anode water is low







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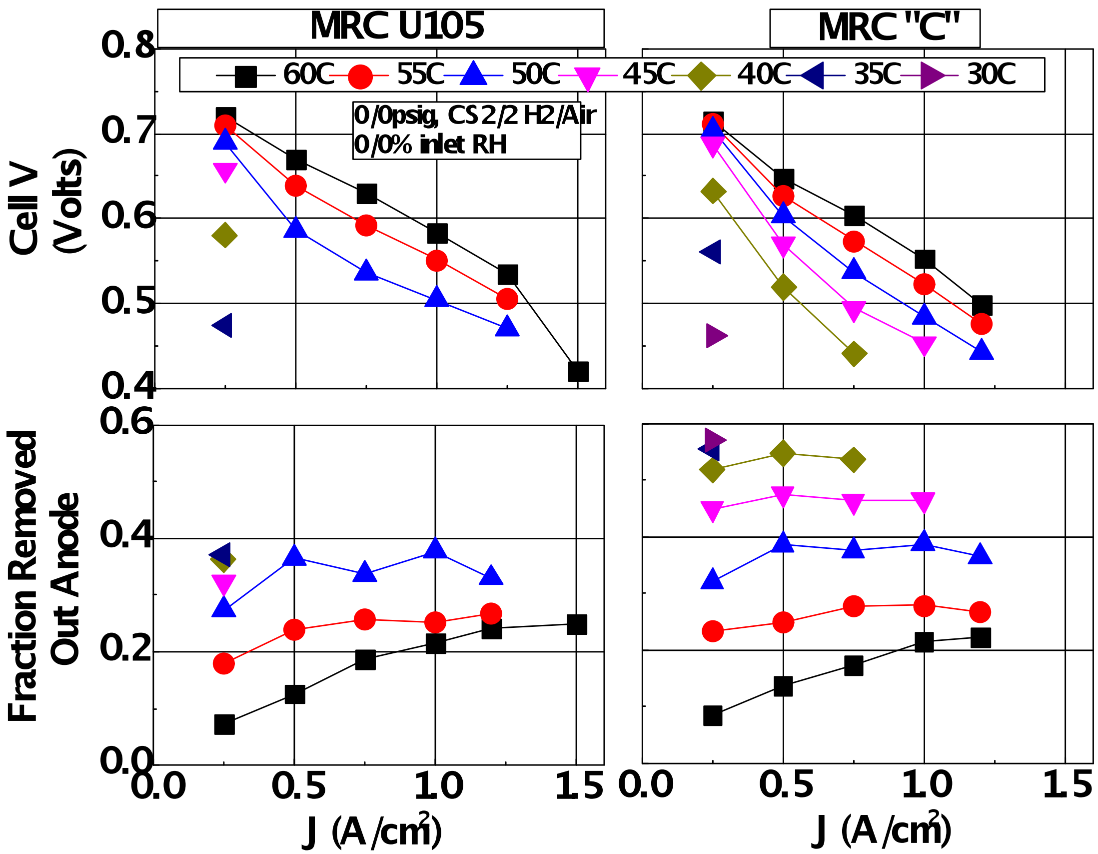
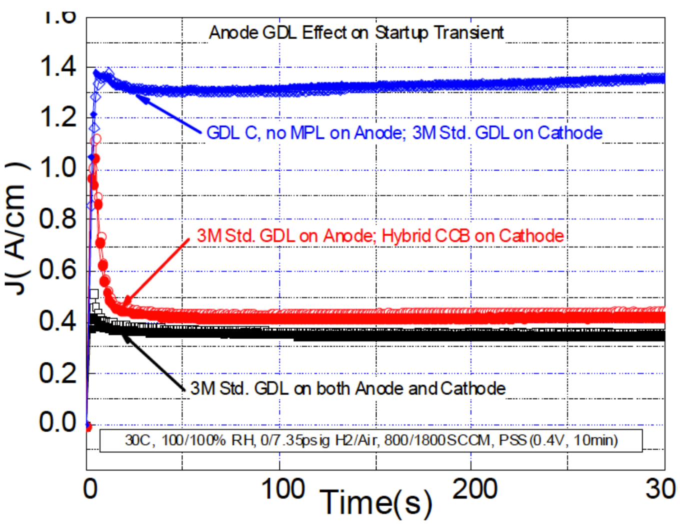
NSTF MEAs

3M NSTF : Water Management

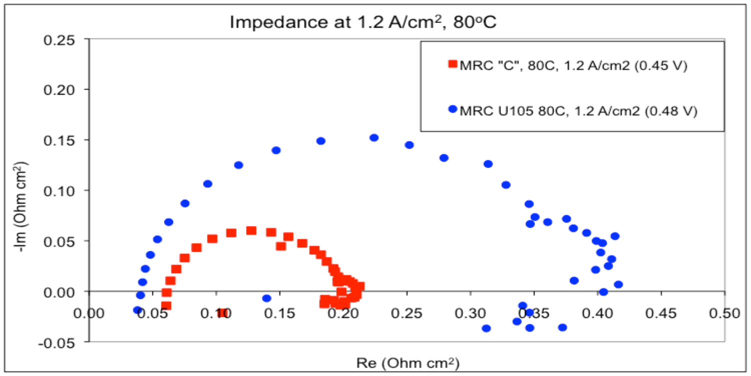
A. J. Steinbach, M. K. Debe, J. L. Wong, M. J. Kurkowski, A. T. Haug, D. M. Peppin, S. K. Deppe, S. M. Hendricks, and E. M. Fischer*ECS Trans.*, **V33(1)**, p47 (2010),

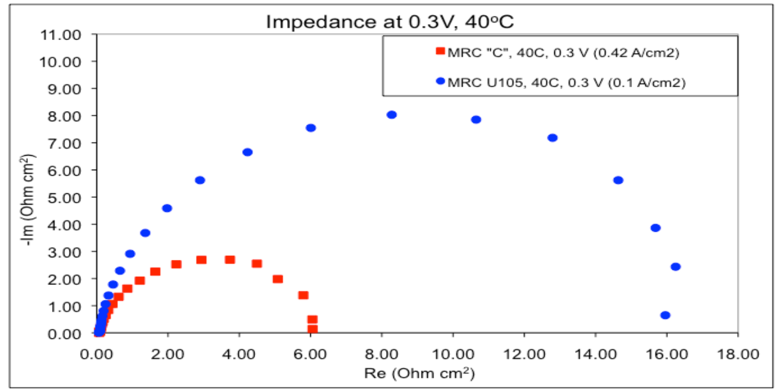


- Water removal through anode
  - GDL variations
  - Pressure variations



Imaging results (NSTF)

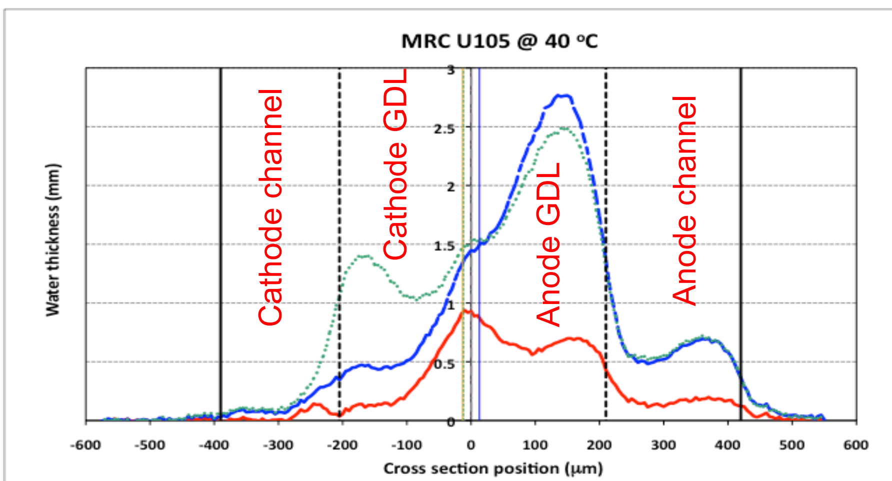




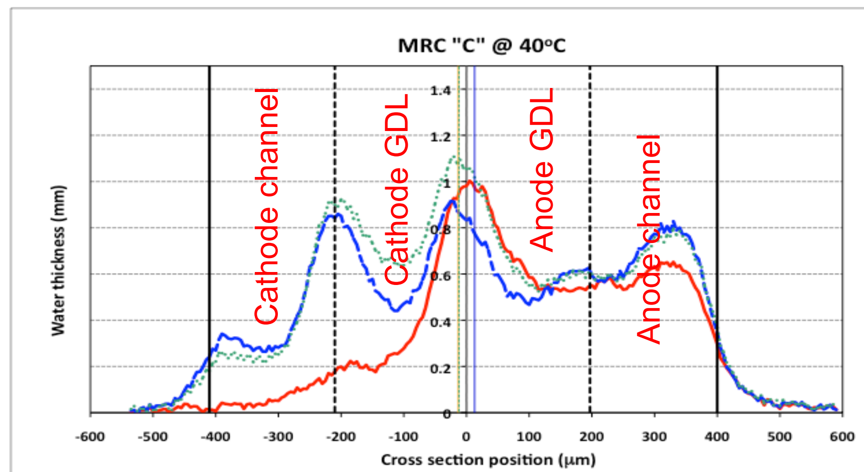
New anode GDL: 4X higher current at 0.3 V, yet less water in the MEA and lower impedance

MRC U105

MRC "C"



OCV
0.3 V
0.1 V



Non-precious metal catalyst based MEAs

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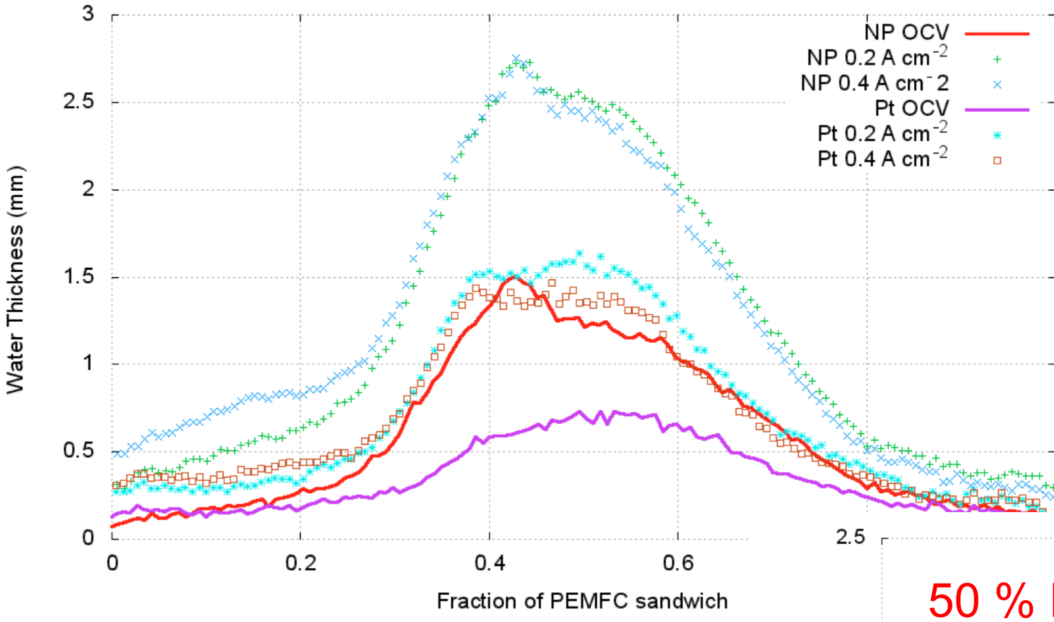
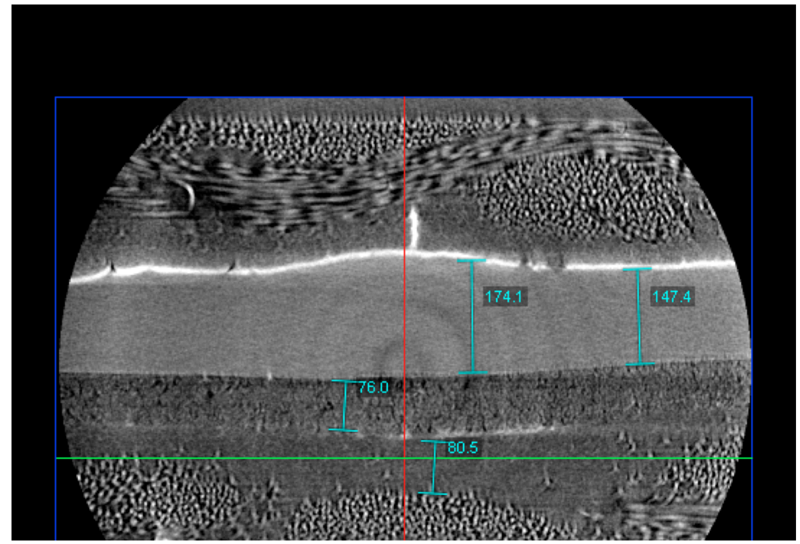
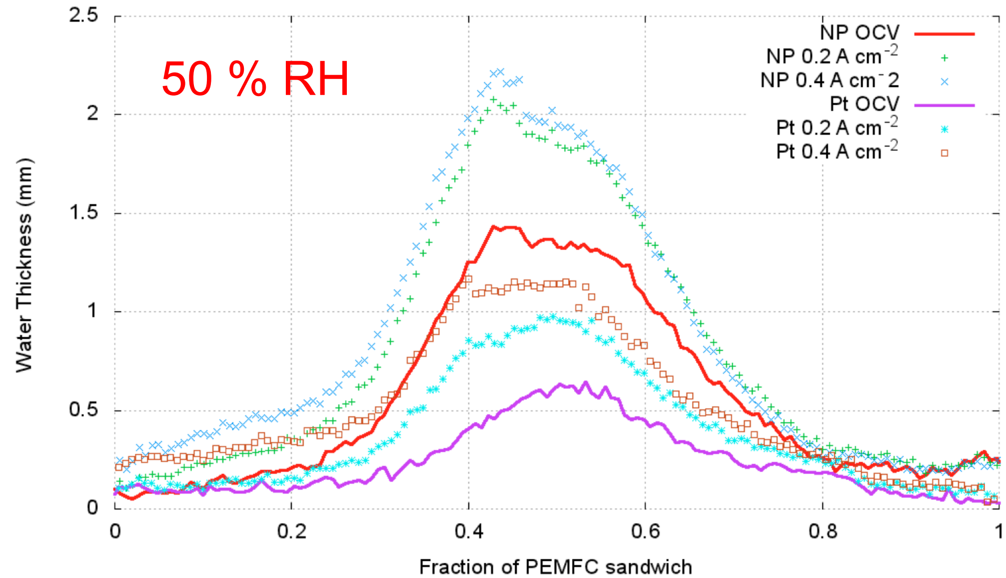
Water content (non-PGM catalyst)

100 % RH



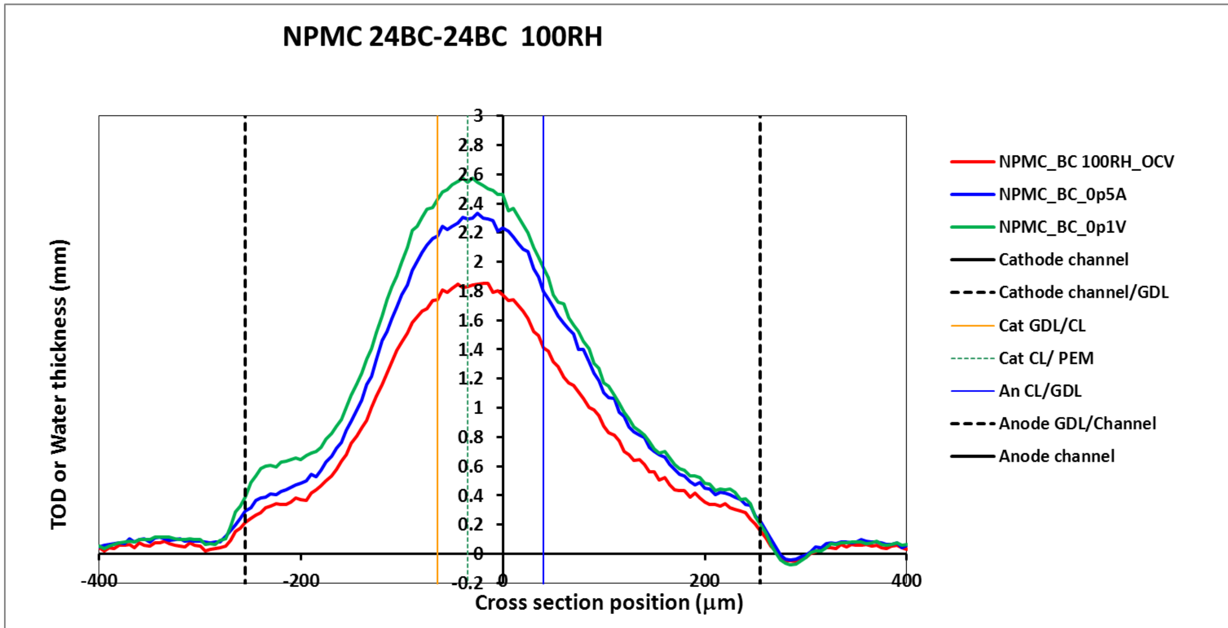


50 % RH



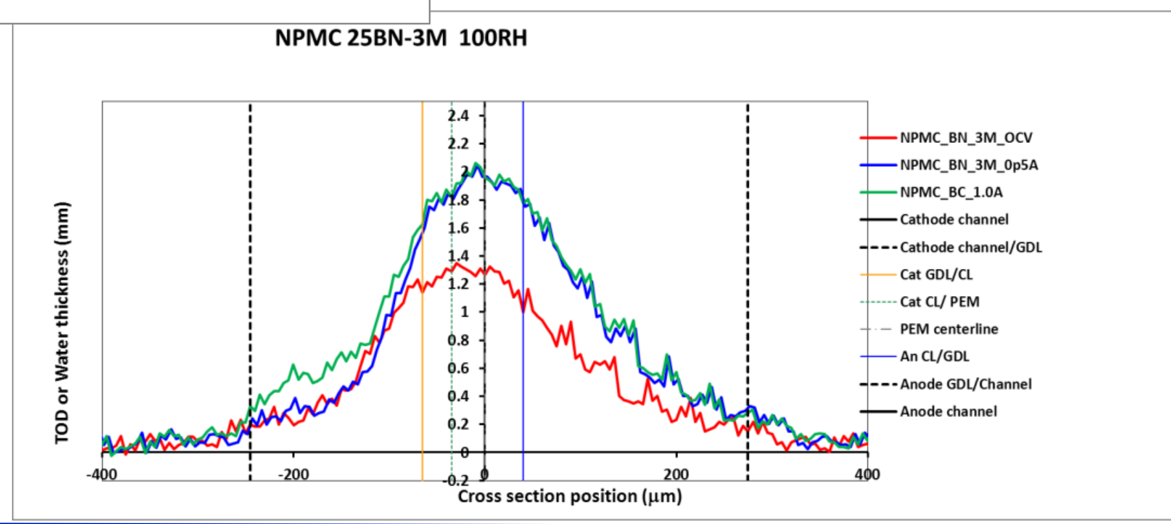
Neutron Imaging shows ≈ 2X more water in Non-PGM MEAs compared to similar Pt/C based MEAs. This is true irrespective of operating conditions

Managing water by varying GDLs (non-PGM MEA)



Water peak at cathode catalyst layer

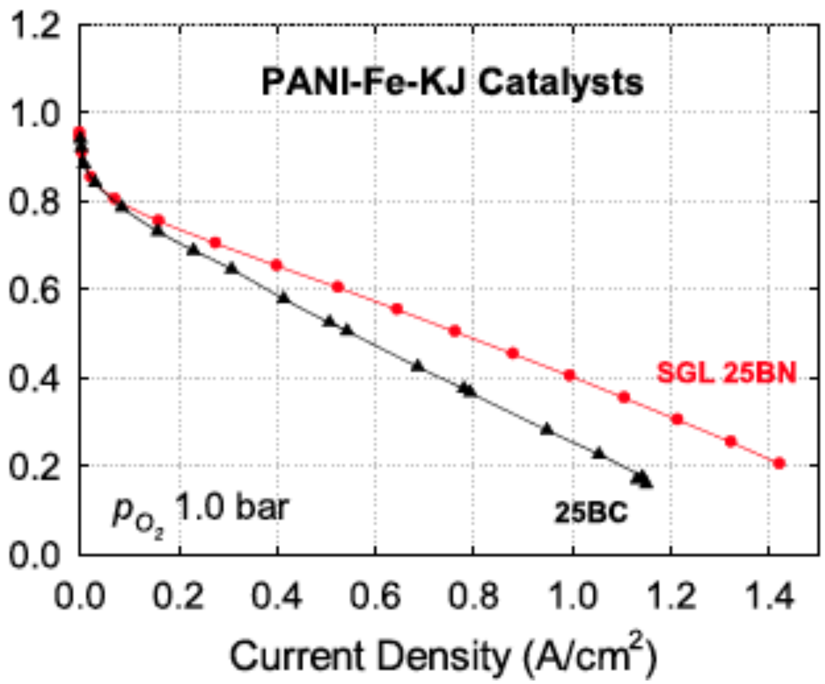
Increases with increasing currents with conventional GDLs



Lower water contents in cathode with 3M anode and BN cathode GDLs (Removal of water through anode)

Fuel Cell Performance of PANI-Fe-KJ Cathode Using Different GDL

Anode: 2.0 mg cm^{-2} Pt; Cathode: 4.1 mg cm^{-2} Cell: 80°C; 100% RH, Membrane: Two Nafion® 212



Mass transport significantly affects performance at $i \geq 0.2$ A/cm^2

- As we use commercial anode GDE, GDL used in the anode for both MEAs are the same.
- Significant performance enhancement in mass transfer range was observed with advanced cathode GDL.

Summary/Future work

High resolution neutron imaging used to study/ optimize fuel cell performance

- Control water removal to minimize catalyst layer water content
- GDL water content indirectly controls performance
- Anode water removal is viable strategy for emerging fuel cell cathodes

Future Work

- Improve resolution and cell design to directly quantify cathode water saturation levels